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REVIEW

Strategies for Controlling the Apple Snail *Pomacea canaliculata* (Lamarck) (Gastropoda: Ampullariidae) in Japanese Direct-Sown Paddy Fields

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Abstract

The apple snail *Pomacea canaliculata* becomes a much more serious pest in direct-sown rice fields than in transplanted fields. In south Japan, it represents an important constraint on the implementation of direct seeding. Described here are possible measures to control the snails and suggestions for its management in Japanese direct-sown rice fields. Crop rotation with upland crops is a practical way with the lowest extra cost. The apple snails were often not eradicated by growing an upland crop in the previous summer. However, snail densities always decreased below the control threshold in direct-sown fields (0.5 snails/m^2). Longer drainage period after sowing greatly reduced snail damage. Thus, draining fields for 10 to 20 days after sowing is a basic practice to control snails in direct seeding. Tillage and puddling have a function to crush snails and, thus, reduce snail densities. "Intensive tillage", in which a field with compacted hard soil is tilled shallow with faster cultivator rotation, achieved higher snail mortality. It is recommended to lower the risk of snail damage after unexpected heavy rain. An application of bait type metaldehyde showed enough control effects to avoid rice damage by snails even in heavy rain conditions. The stable effects seemed to be due to the active ingredient in the bait type which is dissolved slowly. Improving techniques for weeding and for draining fields effectively are necessary for better snail management in direct seeding.

Discipline: Plant protection
Additional key words: golden apple snail, management, rice, direct seeding

Introduction

The apple snail *Pomacea canaliculata* (often referred to as the golden apple snail in Southeast Asia) was introduced to Japan and many other countries in Southeast Asia in the early 1980s[4,5,10,14]. This fresh water snail from South America was initially introduced to Asia as a source of human food. However, commercial markets failed, and discarded or escaped snails invaded rice ecosystems. In Japan, damage to rice by the snail was first recorded in 1984[7]. The distribution of the snail gradually expanded mostly in Kyushu, south Japan and reached ca. 65,000 ha of paddy fields by 2001. Rice damage by snails also increased to a maximum of ca. 13,000 ha of paddy fields in 1999.

Management of apple snails has generally achieved good results in transplanted rice fields in Japan[15,20,25]. Snails do not feed on transplanted rice in shallow water. Keeping paddy water shallow thus helps to control snail damage and is now the most commonly used management practice. Transplanting older rice is also effective because rice gradually becomes tolerant to the snails as it grows. Using these two cultural practices, with occasional pesticide applications, snails can be reasonably well controlled in transplanted rice[20,25]. However, in poorly leveled paddy fields or in regions where very young seedlings are transplanted, the apple snail still remains an important rice pest, which can be very difficult to control.

The Japanese Government has encouraged rice farmers to adopt direct seeding of rice to reduce the cost of production. In direct seeding, however, the snails pose a serious threat because they feed avidly on very young seedlings. Rice farmers cannot adopt this practice in areas where the snails occur. Apple snails represent an

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important constraint on the implementation of direct seeding of rice in South Japan[20,21,25]. Thus, a 4-year research project from 1997 was conducted to overcome this snail problem in Japan. Described here are some of the project outcomes including tentative strategies for controlling the apple snails in direct-sown rice fields of Japan.

Damage by the apple snail to direct-sown rice

The apple snail becomes a much more serious rice pest in direct seeding. Snails feed on sprouts and very young seedlings in direct seeding. Snail infestation results in small or large areas without seedlings scattered throughout a paddy field. Small snails, which are disregarded in transplanted fields, are harmful. Snails larger than 15 mm (shell height) can infest transplanted seedlings with 3.0 leaf-age, while even the hatchlings with a shell height of 3 mm feed on germinating seedlings (Table 1). In addition, a snail consumes a large number of small seedlings. For example, in an experiment conducted in semi-field conditions, a snail with 24 mm shell height had the potential of preventing more than 400 seeds from establishing, when snails had been released just after sowing (Table 2). A snail with the same size caused about only 3 missing seedlings, when snails were released after the seedlings reached the 3.8 leaf-age (same age as transplanted seedlings). In this sense, the snail is 150 times more serious in a direct-sown field than in a transplanted field.

Control measures

Various direct seeding types have been implemented in Asian countries. These are roughly classified to two types: dry seeding and wet seeding. Snail damage does not occur in dry-seeded fields, where rice seeds are sown and young plants are kept in a dry condition. But dry seeding is often not adopted by rice farmers mainly because of weed problems and water leaking after irrigation. Various types of wet seeding in which rice seeds are sown in wet puddled fields, are implemented in Asia. Among wet seeding procedures, water management after sowing and seeding rate are highly influential in snail management. In Japanese wet seeding, a short drainage period (ca. one week) after sowing and low seeding rate (30 kg or less dry seed weight/ha) are recommended. However, these practices favor snail infestation. The following describes control measures for the apple snail in wet seeding, mainly in Japan.

1. Drainage after seeding

Drainage after sowing greatly reduces snail damage[2,21]. Based on an experiment conducted in semi-field conditions, no rice plants established at the density of 2 snails/m^2 in conventional Japanese direct seeding, where the field is irrigated just after sowing (Table 2). About 20 and 70% of rice plants established as compared with the control plots without snails, when the plots were drained for 7 and 10 days, respectively. In two-week drainage, about 90% of plants established. Three weeks of drainage, when the plant age at irrigation was about at the 5 leaf-age, could almost completely prevent damage

Table 1. Size of snails and their capability of attacking rice seedlings with various plant ages

Shell height (mm)	Germinating seed	Imperfect leaf	Plant leaf-age				
			1.0	2.0	3.0	4.0	5.0
Hatchling	△	×	×	×	×	×	×
5.0	○	○	×	×	×	×	×
7.5	○	○	○	×	×	×	×
10.0	○	○	○	△	×	×	×
12.5	○	○	○	○	△	×	×
15.0	○	○	○	○	○	×	×
17.5	○	○	○	○	○	×	×
20.0	○	○	○	○	○	△	×
22.5	○	○	○	○	○	○	○
25.0	○	○	○	○	○	○	○

○ : Snails capable of feeding on the seedling. △ : Snails partially damaging to the seedling.
× : Snails causing no damage.

Table 2. Effect of drainage after sowing on reducing plant damage by *Pomacea canaliculata* (Wada et al.[21]; modified)

Plot	Duration of drainage (days)	Snail density[a)] (snails/m^2)	Plant age[b)] in leaf no. at irrigation	No. of plants established at the final census (SD.) (plants/m^2) [c)]			Relative % of plants established[d)]	Estimated no. of plant loss by a snail
A	0	2	–	0	(0)	a	0	433.5
B	4	2	–	0	(0)	a	0	161.9
C	7	2	1.5–2.1	15.5	(0)	b	17.5	30.9
D	10	2	–	62.3	(6.0)	c	70.1	9.5
E	14	2	3.6–4.1	77.5	(4.3)	d	87.3	3.1
F	21	2	4.6–5.3	88.0	(2.1)	e	99.2	0.9
Control	7	0	1.5–2.1	88.8	(1.8)	e	100	0

a) : Snails with 22.5–25.5 mm were used in the experiment.
b) : The plant age in leaf number without an incomplete leaf.
c) : Within a column, treatments followed by the same letter are not significantly different at the 5% probability level.
d) : Percentage of established plants in each treatment relative to the number of established plants in the controls.

by snails. Thus, when a field is drained for long periods after sowing, snail damage is effectively reduced.

However, there are two problems associated with a long drainage period. The first is weeds. Weed problems are exacerbated by increasing the period of drainage. Fortunately, a new herbicide solves the problem to a considerable extent. Cyhalofop-butyl can control barnyard millets *Echinocloa* spp. younger than the 5 leaf stage. Thus, almost all weeds can be eliminated, if a herbicide containing cyhalofop-butyl and bentazone is applied in drained fields before barnyard millets grow beyond the 5 leaf-age (about 18 days after sowing when rice is at the 4 leaf-age). Two herbicide applications at sowing and at irrigation may be another way to cope with weed problems in a long drainage period, and the selection of herbicides has been investigated by Kojima (personal communication).

Another problem is heavy rain. Since farmers practice direct seeding in the rainy season in South Japan, it often rains heavily, causing standing water in fields during the drainage period after sowing. Then, the snail infestation spreads rapidly. Heavy rain during the sowing season causes very serious snail problems in South Japan. Making ditches[2] or ridging[13] can enhance drainage, but neither of these is fully successful.

2. Mechanical control

Tillage and puddling crush snails. The effect is greater on large snails. By comparing the snail densities before and after tillage or puddling, we evaluated snail mortalities in a field (Wada et al., unpublished data). When the average snail size was 12 mm, the mortality was 68% by tillage plus puddling. When the average snail size was 21 mm, 67% mortality was attained by puddling only. The other experiments were conducted by Takahashi et al.[16], using a large chamber specially designed for evaluating snail mortalities. In their experiments, 40–90% of snails bigger than 25 mm were killed by a rotary cultivator on a tractor (Fig. 1). Snail mortalities by tillage were 14–20% higher when soil was compacted in autumn after rice harvest than those from comparatively friable soil in early summer after the harvest of wheat, a winter crop. Deep cultivation is not necessary because 80% of snails are found within a 6 cm depth of soil during winter[18]. Generally, higher mortality was attained by "intensive tillage" where a field with compacted soil is tilled shallow with a faster cultivator rotation, resulting in smaller cultivation pitch. Takahashi et al.[17] compared snail densities and subsequent rice damage between two paddy fields tilled intensively (velocity: 9.2 cm/s, pitch: 13.7 mm) and ordinarily (velocity: 30.5 cm/s, pitch: 45.7 mm) in the previous autumn. The result was clear that large snails had been eliminated and much

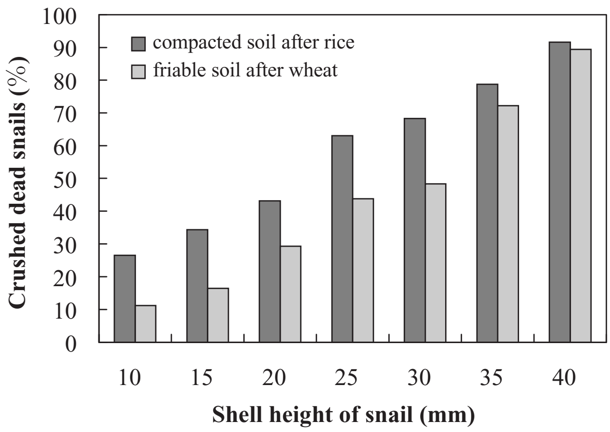

Fig. 1. Percentage of snails killed by tillage in relation to the snail size (Takahashi et al.[16]; modified)

less damage was observed in the field tilled intensively. Snail mortalities may increase by modifying a rotary cultivator with extra straight blades (Takahashi, personal communication).

3. Chemical control

IBP and a few insecticides (cartap, bensultap, etc.), which can suppress rice damage by snails in transplanted fields, have been registered as chemicals for controlling snails in Japan. However, these chemicals do not have sufficient effects in direct-sown fields. In addition, niclosamide, endosulfan, camellia seed cake (residue), copper sulfate, etc., which are often used to control the apple snails in Asia, cannot be registered in Japan because of their side effects or environmental disturbance they cause.

Bait type metaldehyde (10% active ingredient) is a promising pesticide in direct-sown fields and will soon be registered in Japan. A heavy rain has comparatively less influence on its effect since it is a bait type pesticide with slow dissolution of the active ingredient. Its application after sowing followed by 10-day drainage[3] or 18-day drainage[23] (Table 3) successfully suppressed rice damage in spite of heavy rains during drainage periods. Thus, an application of metaldehyde in combination with drainage after sowing has sufficient control effects on the apple snail in direct-sown fields even under conditions of heavy rain.

Calcium cyanamide is another comparatively environment-friendly molluscicide. It was originally used as a fertilizer containing nitrogen and calcium. Thus, nitrogen fertilizer should be reduced on its application before sowing. Twenty-five kg calcium cyanamide (proper amount/10 a for its application) corresponds to 5 kg nitrogen. It has phytotoxicity, therefore farmers have to apply this chemical 7 to 10 days before rice sowing. This delay in sowing decreases the popularity of using this chemical for farmers who grow rice soon after a winter crop. This delay in sowing can be shortened to some degree by extra puddling or by coating seeds with an oxygen supplier (Calper)[11,12].

4. Crop rotation

Crop rotation is a practical way to cope with the snail problem in direct-sown fields in Japan. According to the governmental policy against overproduction of rice, Japanese rice farmers cannot grow rice in 30–40% of their fields in South Japan. The alternative crop planted in paddy fields is often soybean. Consequently, it is not difficult for farmers to have fields available where upland crops were planted in the previous summer. Although the snail was often not eradicated by one year of soybean planting, the snail density decreased greatly[24]. We investigated densities of the snails in the two kinds of paddy fields: the fields where soybean, or rice had been planted in the previous year, respectively (Fig. 2). Snail densities were very low in all paddy fields after soybean in two regions (Fukuoka and Kumamoto Prefectures) of South Japan, while snail densities in the fields after rice

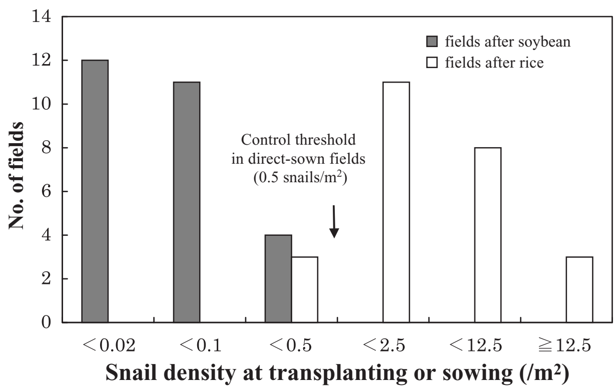

Fig. 2. Snail densities in the fields which were planted with soybean as a summer crop in the previous year (fields after soybean), as compared with those in the fields without crop rotation (fields after rice)

Table 3. Establishment of rice plants after the application of metaldehyde or IBP in a direct-sown field[a)] (Wada et al.[23]; modified)

Treatment	No. of applications	No. of plants/m^2 (mean ± SD)		
		8 DAS	17 DAS	27 DAS
Metaldehyde	1	96.9 ± 11.7	73.9	86.1 ± 9.0
IBP	2	36.0 ± 21.6	25.1	38.5 ± 19.6
IBP	1	48.6 ± 30.7	36.8	47.9 ± 33.8
No applications	0	32.6 ± 21.8	13.8	26.8 ± 19.1
No snail	0	88.6 ± 15.6	91.3	90.7 ± 14.6

a): The field was drained for 18 days after sowing. The initial snail density was 2.6 /m^2.
DAS: Days after sowing.

were usually high. It was noted that the snail densities after soybean were always low enough to avoid damage by the snails, in comparison with the tentative control threshold in direct-sown fields (0.5 snails/m^2)[9]. Mortalities in the snails during the upland crop culture seem to be caused by desiccation and tillage.

5. Biological control

Duck grazing in fields during the fallow period is a common practice to reduce the snail densities in Southeast Asian countries[1,19]. However, duck grazing is usually not practical in Japan. There is little market for duck in Japan and, hence, keeping ducks requires higher cost. Another effective biological agent is fish. In particular, a carp with pharyngeal teeth has a high potential for preying on snails. In fact, the common carp, *Cyprinus carpio*, revealed effective predation in field experiments[6,8]. However, utilization of fish may not be practical, since fish culture requires keeping deep water in fields, but this is often not compatible with modern farming methods. Natural enemy fauna against apple snails are very poor in paddy fields and, thus, population explosions of snails always occur there. On the other hand, many kinds of predators have been recorded in rivers, ponds, and waterways (Yusa et al., submitted). Therefore, biological control of the apple snail in water bodies including irrigation canals, ponds etc. is more probable than its application in paddy fields.

Strategies for controlling apple snails in Japanese direct-sown fields

Crop rotation is the most recommended strategy in Japan. If the farmer has a field available, which was planted with an upland crop in the previous year, he can adopt wet seeding with the lowest additional cost. Prevention of snail entry from waterways is often necessary. Just setting a nylon net at the water inlet solves the problem. If crop rotation is not possible, management using a longer drainage period after sowing with occasional application of bait-type metaldehyde is practical. In the case of high probability of heavy rain, metaldehyde can be applied to the entire area of a field soon after sowing at the beginning of the drainage period. Spot application of the chemical may also be a practical strategy when it is applied only to the areas where standing water exists in the field after rain. In order to lower the risk of snail damage after unexpected heavy rain, it is important to reduce snail densities in advance before sowing. "Intensive tillage" before sowing or in the previous autumn is recommended for this purpose.

The optimal extent of drainage after sowing should be determined by considering the local status of both snail and weed pests. Two- or three-week drainage after sowing almost completely avoids rice damage by snails, if the field is drained sufficiently. However, if drainage is increased for more than 10 days, a foliage application of a herbicide containing cyhalofop butyl is necessary during the draining period. Another herbicide application is sometimes required after introduction of water, but this application may be omitted by use of apple snails for weeding[22]. If the drained period is shorter than 10 days, granular herbicides can be used after introduction of water. Application of a granular herbicide is laborsaving as compared to a foliage application, especially for farmers possessing small fields.

There are some research issues for improving the snail management in direct-sown fields. The technology to drain a field effectively should be studied more under rainy conditions. However, this is basically a problem of the paddy field infrastructure. Leveling of the field is very important for effective drainage. Prevention of overflow in waterways is also required. Thus, wet seeding needs well-leveled fields and a good irrigation scheme. Research for improving weeding techniques is also necessary when a long drained period is used after sowing.

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